The Phasing of Fast Mechanical Neutron Beam Choppers to the SNS

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1 Introduction

The need to produce a 1 µS (FWHM) pulse of 1 eV neutrons over a beam aperture of 50 mm x 50 mm with a phase stability of ± 0.3 µs with respect to the SNS neutron pulse on the High Energy Inelastic Spectrometer (HET) is the most demanding requirement for any of the SNS choppers. Our chopper development and testing programme has therefore been largely directed towards satisfying this specification.

A Fermi-type fast chopper spun at 36000 rpm on a modified Harwell Mk VIII spinning head and controlled by a new digital electronic control and drive system designed at the Rutherford Laboratory has been developed for this purpose. In order to monitor the phase stability, an optical transducer (OPTO) which senses the actual motion of the top of the chopper rotor body, was mounted within the vacuum spinning tank. Whereas normally chopper spinning systems are synchronised to crystal clocks, one of the proposed SNS operating modes ("locked to the mains") required that an investigation be made into the possibility of operating synchronised to the machine at ∿ 50 Hz.

2 Chopper Development

Two prototype chopper rotors have so far been produced. These consist of a 120 mm dia cylindrical body machined from a solid block of aluminium alloy and are pierced diametrically by a 56 mm x 52 mm aperture which contains the slit package. The slit package is an assembly of ∿ 50 neutron opaque 'slats' cut from a sheet of a matrix of boron fibres diffusion-bonded into aluminium; the slats are interleaved with neutron transmitting 'window frame' slits etched from 0.4 mm thick aluminium alloy foil. The two rotors differ in that one set of slats is of a single ply boron/aluminium matrix whilst the other is a triple ply boron/aluminium alloy matrix with a 90° lay up. Profiled cheek plates are used to curve the slit package to a cylindrical radius of 1.84 m which at 36000 rpm optimises the transmission of the rotor for 1 eV neutrons. Both these rotors have been successfully spun for several weeks at their design speed and have been spun at speeds producing up to 25% overstress for short periods without any measureable change of parameters. An experimental programme to test their neutron transmissions and pulsing properties will commence when the new Harwell electron linac comes into operation.

Mechanical aspects influencing the Phase Stability of the Rotor when operated from a Fixed Frequency Source

It was decided at the outset of our chopper development programme to use the Harwell Mk VIII spinning head as the drive for our chopper rotors. Consequently much of the experience and procedures developed at Harwell were transfered directly into our programme. In general this has proved to be entirely satisfactory however a much more precise phase stability is needed for the HET application (± 0.3 µs) than has been customary and this has necessitated making several modifications. These are as follows:

i) Modifications to the Damper Mechanism

The drive from the spinning head is coupled to the chopper rotor by a flexible steel shaft 2 mm diameter and 200 mm long. This shaft traverses a dynamic oil vacuum seal and a sliding-plate damper mechanism. The function of the latter is to limit shaft whirls which develop due to imbalances and resonances of the shaft and chopper drive during the spin-up to its operating speed.

The Harwell damper, which is essentially a brass disc frictionally constrained between two rubber 'O' rings, did not give a consistent action over its lifetime and tended to stick and become non-central when the rotor was at its operating speed. This caused a residual bend in the shaft and led to precession of the rotor. These shortcomings have now been rectified by
a) having a more precise tolerance in the hole linking the disc to the shaft,
b) the substitution of PTFE for rubber in the 'O' rings and, c) by adding a wave-spring washer to provide compression.

ii) Dynamic Balancing of the Chopper Rotors

Although some Harwell chopper rotors were dynamically balanced during manufacture it was generally found adequate simply to check their balance statically by rolling them on precisely levelled knife edges. However, the replacement of the Harwell magnetic pick-up coil at the top of the spinning head by OPTO sensors, which measured directly the actual motion and phasing of the chopper rotors revealed that, although grossly stable, statically-balanced rotors still had small imbalances which caused precessional and sometimes also vibrational motions to occur at the end of the flexible drive shaft. These sometimes resulted in phase variations of several microseconds with a periodicity ranging from less than one second to several tens of seconds.

To eliminate these precessional motions our chopper rotors are now dynamically balanced on specially adapted machines to a precision 5 times better than that used in the Harwell procedure. We believe that by refining our mounting and driving techniques the balancing will be further improved.

iii) Coupling of the Chopper Rotors to the Spinning Head

Zero precession can only be achieved when the axis of rotation of the rotor in its assembled spinning configuration is concentric with the axis of balance as established in ii) above. This requires that each of the mating surfaces between the flexible shaft, split collet, conical seating, threaded boss and oil-thrower nut which join the chopper rotor to the spinning head should be manufactured to close squareness and concentricity tolerances.

The Harwell specified tolerances were not sufficiently stringent to ensure that this condition was adequately fulfilled for our needs. We are currently modifying the collet design and retolerancing to meet the upgraded phase stability requirement for the HET spectrometer.

4 Results from Fixed Frequency Operation

When the above conditions are satisfied and the rotors are driven at a fixed frequency derived from a crystal clock using the electronics described in the following paragraphs, it has been possible to achieve long and short term phase stabilities better than ± 0.3 μs.

5 Drive and Control Electronics

The spinning head consists of a hysteresis motor mounted vertically running in air bearings and supported by a magnetic thrust bearing. Electronic circuits are therefore necessary to produce a three phase supply of the correct frequency together with some means of rotating the phase of the drive to align the rotors to the required angle. In general several rotors systems are needed and each must be capable of retaining a fixed phase relationship with a primary master timing pulse (50 Hz) to ± 0.3 μs at spin speeds of 600 Hz. This requirement even at fixed operating frequencies needed careful design to eliminate, as far as possible, all the static errors present and a servo loop was used to maintain its positional accuracy over long periods. Figure 1 shows a block diagram of the angular reference required for the digital system. A primary pulse frequency multiplier and time-of-flight programmable delay is also included in the diagram. The delay sets the time from beam extraction to the rotor open instant. The angular reference is a high speed phase locked loop which in effect divides each rotation of the chopper into 10,000 parts. The output is then a scalar in BCD which is used as anangular positional reference for a circulating store in the digital control loop. The Voltage Controlled Oscillator (VCO) output of 10,000 pulses per master pulse is used to develop reset pulses for a ROM based three phase static alternator to drive the hysteresis motor.

The rotor phase controller (Figure 2) is a phase locked servo loop. The demand position is developed from the scaler and in this system can be selected from 1 of 1000 points by switches. The demand is therefore both a velocity and position reference. A pulse developed by an optical transducer on the chopper is then compared to the demand position in a phase comparator and the error is converted to a pulse train which clocks a counter either up or down for an advance or retard error. The up/down counter is compared to the scalar and the coincident pulse modifies the phase of the drive in the static alternator to the hysteresis motor in the direction necessary to eliminate any error. The increments of correction are 1/10,000 of a chopper rotation period at an adjustable rate dependent on the system requirements. In order to make the system operate to the high limits of accuracy required all switching circuits are designed for synchronous operation. The phase characteristics of the motor load combination are that of a second order system with almost zero damping, compensation networks are therefore included to damp out unwanted torsional oscillations. An analogue signal proportional to the low frequency instabilities of the rotor is developed and, after compensation, is fed back to the digital control loop via a voltage controlled phase shift circuit. The compensation networks required depend on the system characteristics ie chopper, drive power, gain etc.

The static alternator has sine wave programmed read only memories, one set per phase, clocked by resetable counters. The rotor controller provides the necessary pulses to form three phases, 120 degrees apart. Rotation of the phase of the drive is also controlled by the timing of the ROM counter reset pulses. The digital output from each ROM is changed to an analogue signal in an 8 bit digital to analogue conveter which is then fed to conventional power amplifiers and transformed to the correct operating voltage for the hysteresis motor. Using 100 steps per cycle with the amplitude set by 8 bits produces an adequate sine wave.

6 Operation with a Variable Input Frequency

In order to assess the performance as a 50 Hz mains synchronised system a phase locked loop with a long low pass filter time constant was connected to raw mains, effectively removing all rapid frequency changes. The maximum phase error was checked and generally found to be within ± 100 μs with occasional errors of ± 300 μs. The system was then operated from the output of the phase locked loop and the result shown on the chart recording (Figure 3) was obtained. Counters were also used to check the stability of the system and indicated that the chopper remained within ± 0.5 μs of a desired positon for 90% of the total time of the test and approximately 100% of the counts were within a ± 1 μs error. These tests were carried out using a 3.7 kg Fermi chopper which will normally be used on the SNS High Energy Inelastic Spectrometer.

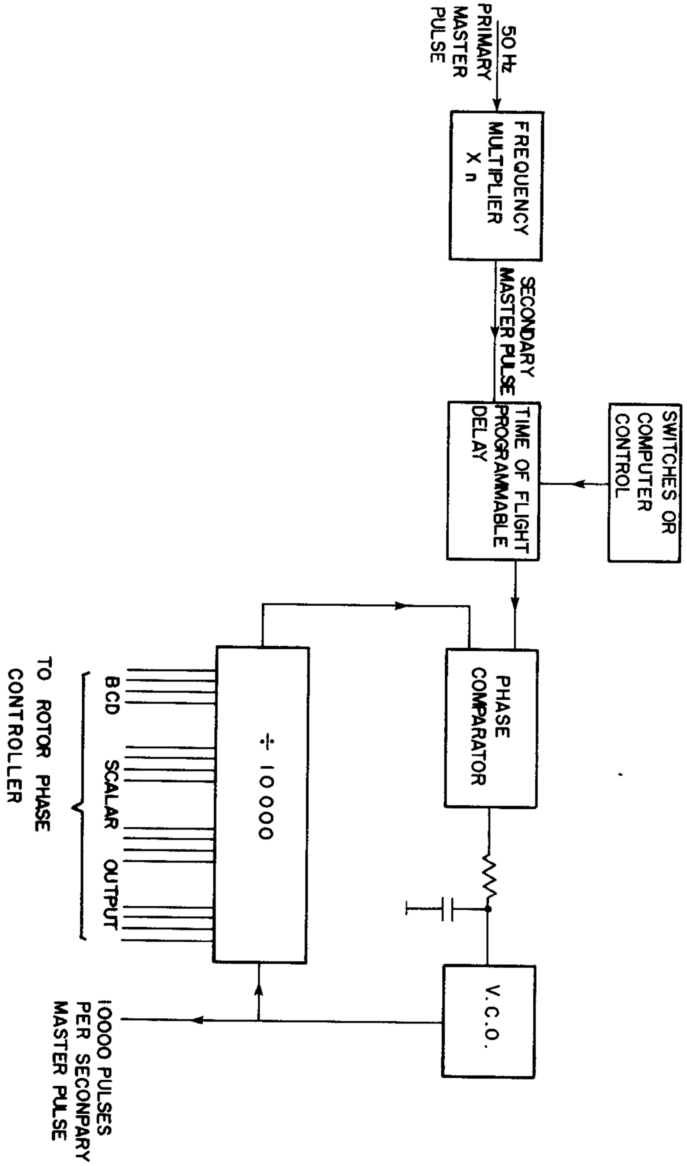

FIG. I. SCALAR

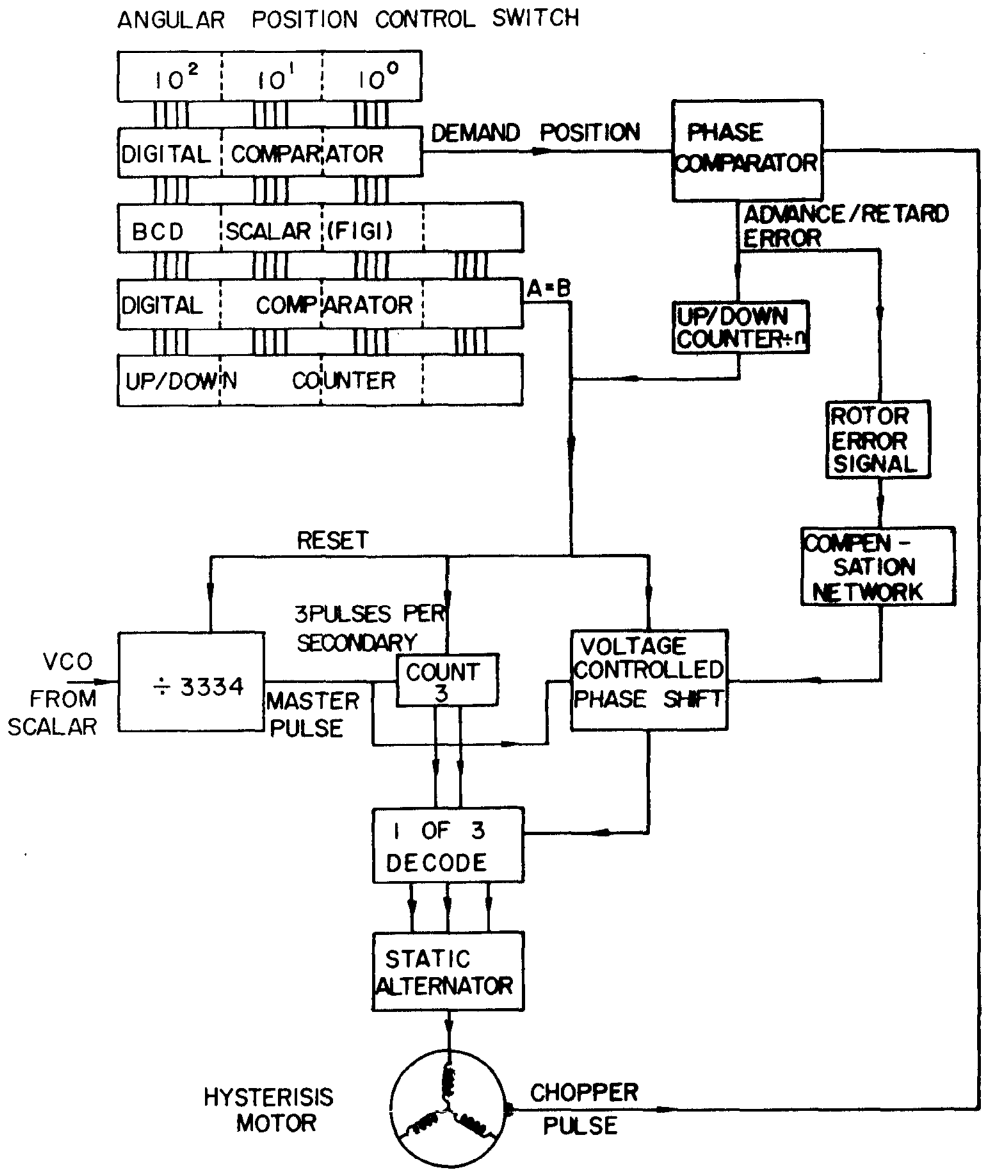

FIG. 2. ROTOR PHASE CONTROLLER

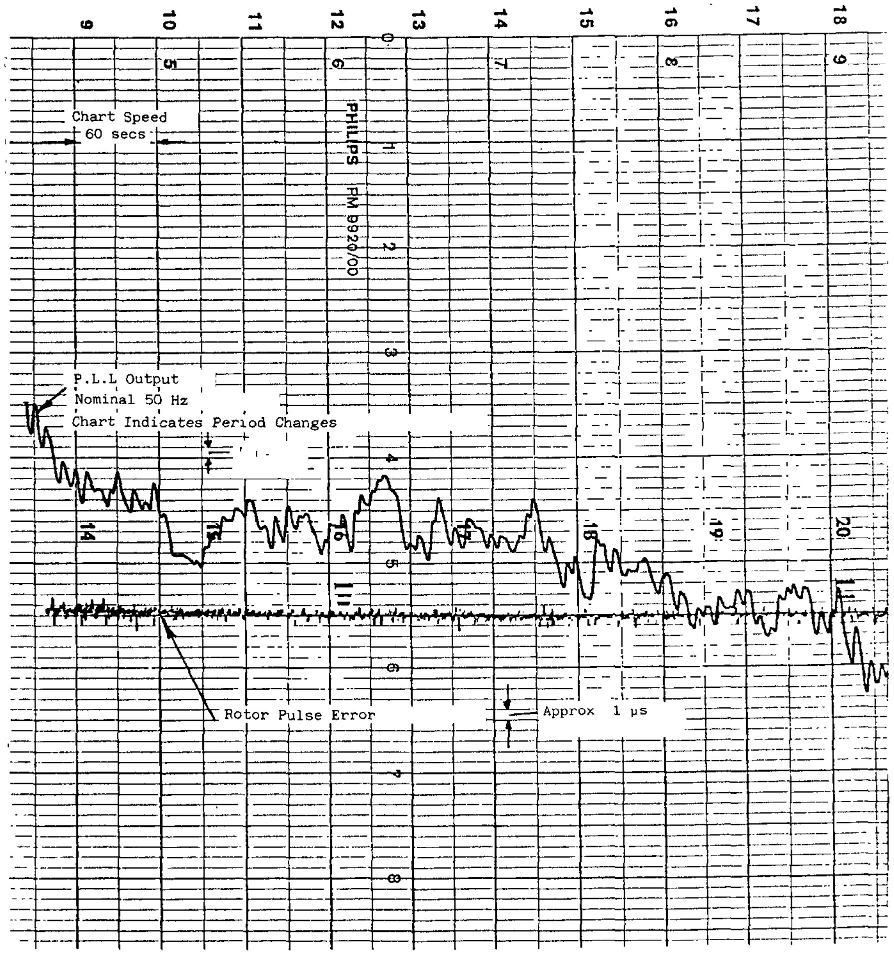

Fig. 3. System Stability Synchronised to a 50 Hz Modified Mains Supply